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(54) **High-speed asynchronous transfer mode packet switching network system having time slot scheduling unit**

Schnelles Paketvermittlungsnetzwerkssystem des ATM-Typs (asynchronous transfer mode) mit einer Einheit für die Zuteilung von Zeitschlitten

Système de réseau à commutation de paquets en mode de transfert asynchrone avec un dispositif d'attribution d'unités temporelles

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## Description

This invention relates to an asynchronous transfer mode packet switching network system and, more particularly, to a time slot scheduling unit incorporated in the asynchronous transfer mode packet switching network system for improving the throughput of packets.

An asynchronous transfer mode packet switching network system is attractive to a data communication established for various kinds of digital data such as, for example, digital voice data as well as digital visual data. The asynchronous transfer mode packet switching network system needs to prevent packets from collision and is usually equipped with packet buffers. Various network systems have been proposed and are classified by location of the packet buffers. In view of large-scale high-speed data communication, it is desirable for the asynchronous transfer mode packet switching network to provide the packet buffers in front of the space division switching unit, and Fig. 1 shows a typical example of the asynchronous transfer mode packet switching network of the type equipped with the packet buffers located in front of the space division switching unit.

Referring to Fig. 1 of the drawings, packet buffers 11 to 1n are, respectively, assigned input ports 21 to 2n, and a series of packets form a queue in each of the packet buffers 11 to 1n. The packet buffers 11 to 1n are coupled in parallel to a space division switching unit 3, and output ports 41 to 4m are associated with the space division switching unit 3. The packet buffers 11 to 1n behave on the FIFO (First-In First-Out) basis, and packets each at the head of the queue are supplied from the packet buffers 11 to 1n through respective internal input links 51 to 5n to the space division switching unit 3. The space division switching unit 3 distributes the packets to the output ports 41 to 4m. However, if a plurality of packets are directed to any one of the output ports 41 to 4m, a contention resolution unit 6 prevents the packets from collision.

In detail, each of the packet buffers 11 to 1n communicates with the contention resolution unit 6 prior to the output of the packet at the head of the queue to see whether or not the output of the packet is enabled. For this reason, the packet buffers 11 to 1n are coupled through inquiring signal lines 71 to 7n paired with respective permission signal lines 81 to 8n to the contention resolution unit 6. If a plurality of packets are directed to any one of the output ports 41 to 4m, the contention resolution unit 6 permits one of the packet buffers 11 to 1n to supply the packet at the head of the queue to the space division switching unit 3 in reply to the simultaneous inquiries through the inquiring signal lines 71 to 7n, but the other packet buffer or buffers wait until permissions at the contention resolution unit 6.

The space division switching unit 3 is implemented by a non-blocking self-routing switching network such as the Batcher-Banyan switching network, and the contention resolution unit 6 is fabricated by using a self-rout-

ing switching network.

However, the prior art asynchronous transfer mode network system thus arranged suffers from a low throughput. This is because of the fact that a packet at the back of a front packet in contention with another front packet is forced to wait even though the designated output port is not busy. In fact, the prior art asynchronous transfer mode network system achieves about 58 % throughput in a random arrival represented by such as M/D/1 model. This problem is known as "head of line blocking" phenomenon.

Various solutions have been proposed for the head of line blocking phenomenon, and a sequential arbitration is effective against the head of line blocking phenomenon (see "Evaluation of The ATM switching System", Proceedings of the 1989 National Spring Conference of Communications, B-385). Namely, some of the packets picked up from the head of each queue are sequentially compared with those in another queue and are subjected to arbitration. Such a sequential arbitration easily finds a non-busy output port and allots the non-busy output port to a packet directed thereto. For this reason, the sequential arbitration increases the throughput of the space division switching unit 3 and is carried out prior to the output from the packet buffers 11 to 1n. If internal input links are scheduled on a reservation table together with internal output links, packets are effectively allotted to the non-busy input and output links. The reservation table is proposed in "Analysis of Time Reservation Controlling Technology for Input Buffers", Proceedings of the 1989 National Spring Conference of Communications, B-437.

However, the prior art sequential arbitration can not drastically improve the throughput of the space division switching unit. In fact, the former achieves about 70 % throughput, and the latter increases the throughput to about 85 %. If packets arrive at the input ports 21 to 2n at a higher rate than the maximum throughput, overflow takes place in the packet buffers 11 to 1n, and, accordingly, some pieces of data information are lost therein. The reason why the throughput is saturated around 70 to 85 % is that the contention resolution unit 6 merely arbitrates contentions between the packets at the front positions of the queues. If all of the packets at the front positions are directed to one of the output ports 41 to 4m, the other output ports stand idle even if a packet directed thereto follows the packets at the front positions.

If all of the packets in the packet buffers 11 to 1n are subjected to arbitration, the output ports 41 to 4m may be kept busy at all times, and, therefore, the throughput is drastically improved. However, the asynchronous transfer mode network system needs to achieve a high-speed packet switching for packets each consisting of 53 bytes on a link at 150 Mbps, and, therefore, any technology currently available hardly arbitrate for all of the packets in the packet buffers.

IEEE INT. CONF. ON COMMUNICATIONS 87, Vol.

1, June 1987, SEATTLE, US, pages 373 - 377; S. GOHARA ET AL: "A NEW DISTRIBUTED SWITCHING SYSTEM ARCHITECTURE FOR MEDIA INTEGRATION" describes a switching network configuration of a central switching module. In particular, a scheduling unit is disclosed for controlling a highway having periodically repeated frames, and a self-routing control logic prevents a packet from a collision with another packet in the space switch unit. Therefore, only a switching sequence for a frame structure having periodically repeated time slots is achieved.

A similar scheduling operation is disclosed in IEEE INT. CONF. ON COMMUNICATIONS 1988, Vol. 2, June 1988, PHILADELPHIA, US, pages 922 - 927; H. OBARA ET AL: "HIGH SPEED TRANSPORT PROCESSOR FOR BROADBAND BURST TRANSPORT SYSTEM".

It is an important object of the invention to provide an asynchronous transfer mode switching network system which improves the throughput of a space division switching unit incorporated therein.

To accomplish this object the present invention proposes to assign packets in packet buffer units to respective time slots where no contention of destination takes place, and an asynchronous transfer mode switching network system according to the invention is defined in the appended claim.

The features and advantages of an asynchronous transfer mode switching network system according to the present invention will be more clearly understood from the following description taken in conjunction with the accompanying drawings in which:

Fig. 1 is a block diagram showing the arrangement of a prior art asynchronous transfer mode switching network system;

Fig. 2 is a block diagram showing the arrangement of an asynchronous transfer mode switching network system according to the present invention;

Fig. 3 is a view showing a format of a packet;

Fig. 4 is a block diagram showing the general arrangement of a packet buffer unit incorporated in the asynchronous transfer mode switching network system;

Fig. 5 is a block diagram showing the detailed circuit arrangement of the packet buffer unit;

Fig. 6 is a block diagram showing the circuit arrangement of a time slot scheduling unit incorporated in the asynchronous transfer mode switching network system;

Fig. 7 is a circuit diagram showing the arrangement of a schedule memory incorporated in the time slot scheduling unit;

Fig. 8 is a circuit diagram showing the arrangement of a time slot determination circuit incorporated in the time slot scheduling unit;

Figs. 9A and 9B are timing charts showing the global circuit behavior of the asynchronous transfer mode switching system network according to the

present invention; and

Fig. 10 is a graph showing the throughput of the asynchronous transfer mode switching network system in terms of average time delay.

## General Arrangement

Referring to Fig. 2 of the drawings, a plurality of packet buffer units 201 to 20n are coupled in parallel to input ports 211 to 21n, and packets are sequentially supplied from each of the input ports 211 to 21n to the associated packet buffer unit 201, ... or 20n. The packets thus sequentially fed to each of the packet buffer units 201 to 20n enter in a queue produced therein. The packet buffer units 201 to 20n are coupled through internal input links 221 to 22n to a space division switching unit 23, and a plurality of output ports 241 to 24m are provided in association with the space division switching unit 23. A plurality of component switching elements as many as (n x m) are incorporated in the space division switching unit 23 and are of the self-routing space switch such as, for example, the Batchen-Banyan switch. The packets are supplied from the respective packet buffer units 201 to 20n through the internal input links 221 to 22n to the space division switching unit 23, and the space division switching unit 23 distributes the packets to the output ports 241 to 24m in so far as no contention takes place between the destination or the output port to be directed.

In order to prevent the packets from collision, a time slot scheduling unit 25 is provided in association with the packet buffer units 201 to 20n, and the packet buffer units 201 and 20n and the time slot scheduling unit 25 are coupled through a first multi-bit bus system 26 and a second multi-bit bus system 27. A synchronous signal is supplied through a synchronous signal line SYNC to all of the component units, i.e. the packet buffer units 201 to 20n, the space division switching unit 23 and the time slot scheduling unit 25, and a system clock signal line CLK propagates a system clock signal to all of the component units 201 to 20n, 23 and 25. The synchronous signal as well as the system clock establish a synchronous control between all of the component units 201 to 20n, 23 and 25.

The packets are formatted as shown in Fig. 3, and each of the packets has three fields PH, PF and DF. The first field VF contains the most significant bit MSB serving as a flag bit indicative of validity of the packet. The second field PF is assigned address bits indicative of one of the output ports 241 to 24m to which the packet is directed, and the third field DF is provided for data bits indicative of, for example, a piece of voice information, a piece of visual information or a binary number. The first and second fields are hereinbelow called as "packet header PH". Although the packet header PH usually contains address bits indicative of a logical address, a priority bit and so forth, these bits do not directly concern the gist of the present invention, and, for this reason, no

further description is incorporated hereinbelow.

The synchronous signal is periodically supplied to the component units 201 to 20n, 23 and 25 and defines a time slot. A series of the time slots are respectively assigned the packet buffer units 201 to 20n, and each of the packet buffer units 201 to 20n sends a time slot request signal through the first bus system 26 upon arrival of a new packet. The multi-bit time slot request signal is representative of the pieces of information memorized in the packet header PH of the new packet, and the time slot scheduling unit 25 provides a time slot assigning signal indicative of the amount of time delay from the present time through the second bus system 27 to the packet buffer unit. The amount of time delay assigns the packet to the earliest time slot which prevents the packet from undesirable collision. With the time slot assigning signal fed from the time slot scheduling unit 25, the packet buffer unit retards the output of the packet until the time slot assigned by the scheduling unit 25 takes place, and, then, sends the packet to the space division switching unit 3. The space division switching unit 3 forms a signal path between the internal input link and one of the output links coupled to the designated output port in accordance with the second field PF incorporated in the packet, and the packet is transferred to the designated output port.

#### Packet Buffer Unit

All of the packet buffer units 201 to 20n are similar in circuit arrangement to one another, and the circuit arrangement of the packet buffer unit 201 is illustrated in Fig. 4. The packet buffer unit 201 largely comprises a packet memory 201a, first and second counter circuits 201b and 201c associated with the packet memory 201a, a control memory 201d, a third counter circuit 201e associated with the control memory 201d, and an adder 201f also associated with the control memory 201d. Packets fed from the input port 211 are sequentially written into the packet memory 201a in accordance with the first counter circuit 201b memorizing a first write-in address sequentially incremented, and the first write-in address causes the packet memory 201a to sequentially store the packets from the leftmost block to the rightmost block by way of example. Each of the blocks of the packet memory 201a stands for a memory location assigned an address, and the address is referred to as "first write-in address" in the write-in operation as well as "first read-out address" in the read-out operation. Only the packet header PH of each packet is transferred to the first bus system 26 upon arrival for requesting the time slot scheduling unit 25 to assign a time slot as described hereinbelow in detail under subtitle "Time Slot Scheduling Unit".

The packets thus sequentially memorized in the packet memory 201a are read out to the internal input link 221 in a random manner in accordance with the second counter circuit 201c memorizing the first read-out

address. The first read-out address is supplied from the control memory 201d to the second counter circuit 201c, and the first read-out address addresses any one of the packets stored in the packet memory 201a. The first read-out addresses are memorized in the control memory 201d in a random manner with reference to a second write-in address fed from the adder 201f and sequentially read out from the leftmost block to the rightmost block, by way of example, in accordance with the third counter 201e designating one of the blocks of the control memory 201d. Each of the blocks of the control memory 201d stands for a memory location assigned an address as similar to the packet memory 201a. The address of each block in the control memory 201d is referred to as "second write-in address" in a write-in operation and as "second read-out address" in a read-out operation. The second read-out address is produced by the adder 201f on the basis of the second write-in address in the third counter circuit 201e and the time slot assigning signal indicative of the amount of time delay or the amount of deviation from the second write-in address. The combination of the packet memory 201a and the control memory 201d thus arranged achieves a global arbitration over all the packets memorized in the packet buffer units 201 to 20n, because the time slot scheduling unit 25 takes into account of all of the packets previously supplied to the packet buffer units 201 to 20n before determination of the amount of time delay or the amount of deviation.

The packet memory 201a, the control memory 201d and the counter circuits 201b, 201c and 201e are fabricated as shown in Fig. 5. The packet memory 201a has a dual port interface 201g coupled between the associated input port 211 and the first bus system 26, and a dual port random access memory device 201h coupled at the data input port DI to the associated input port 211. The data input port DI is associated with a write-in address port WA, and the write-in address port WA is coupled to a counter 201i of the first counter circuit 201b. The dual port random access memory device 201h further has a data output port DO associated with a read-out address port RA, and a strobe port STB supplied with the system clock signal. The read-out address port RA is coupled to the second counter circuit 201c, and the random access memory device 201h simultaneously carries out the write-in operation and the read-out operation. The dual port interface 201g is responsive to the synchronous signal and supplies the packet header to the first bus system 26 when counting a predetermined number of the system clocks. The interface 201g incorporated in each packet buffer unit is assigned a predetermined number different from the other interfaces, and, for this reason, no collision takes place on the first bus system.

The control memory 201d also comprises an interface 201j coupled to the second bus system 27, and a dual port random access memory device 201k has a data input port DI associated with a write-in address port

WA, and the data input port DI is coupled to a register 201l of the first counter circuit 201b which in turn is coupled to the counter 201i. The register 201l is responsive to the synchronous signal and latches the first write-in address therein. Thus, the first write-in address is stored in the register 201l and, then, supplied to the data input port DI of the random access memory device 201k as the first read-out address memorized therein. The third counter circuit 201e keeps the second read-out address which is incremented with the synchronous signal, and, for this reason, the second read-out address allows the random access memory device 201k to sequentially supply the first read-out address to the second counter circuit 201c. The second counter circuit 201c is responsive to the system clock signal and increments the first read-out signal until the synchronous signal allows the next first read-out address to be fed from the next block of the random access memory 201k designated by the third counter circuit 201e. Then, the component bits of one of the packets are successively read out from the block of the random access memory device 201h to the internal input link 221. As described hereinbefore, the first write-in address is memorized in the random access memory device 201k as the first read-out address, and one of the blocks is designated by the adder 201f for the first read-out address fed from the register 201l. Namely, the adder 201f has two input ports one of which is coupled to the third counter 201e and the other of which is coupled to the interface 201j. The interface 201j behaves as similar to the interface 201g in response to the synchronous signal and the system clock signal so that the time slot assigning signal surely arrives at the designation without any confusion. The interface 201j transfers the time slot assigning signal to one of the input ports of the adder 201f, and the time slot assigning signal is representative of the amount of time delay or the amount of deviation from the second read-out address. The amount of time delay or the amount of deviation is equivalent to a number of the time slots after which the packet should be read out from the random access memory device 201h without any collision. Then, the adder 201f produces the second write-in address through adding the amount of deviation to the second read-out address. Since the third counter circuit 201e allows the first read-out address to be read out from the random access memory device 201k to the second counter circuit 201c when the delay time period is expired, the packet is supplied from the random access memory device 201k to the internal input link 221 in the earliest time slot free from any collision. Since the time slot assigning signal is indicative of the number of time slots between the arrival of a packet at the packet buffer circuit and the delivery of the packet, each of the packet memory 201a and the control memory 201d needs to have the memory locations as many as the time slots between the present time slot and a time slot with the maximum time delay.

#### Time Slot Scheduling Unit

Turning to Fig. 6 of the drawings, the time slot scheduling unit 25 is illustrated in detail. The time slot scheduling unit 25 comprises a schedule memory 25a, decoder circuits 25b and 25c, counter circuits 25d and 25e, an inverter circuit 25f, a time slot determination circuit 25g, an encoder circuit 25h and a subtracter 25i. In this instance, the counter circuit 25d and the decoder circuit 25b as a whole constitute packet buffer identifying means, and the encoder circuit 25h and the subtracter 25i form in combination time slot assigning means. The counter circuit 25e serves as standard time signal producing means, and the decoder circuit 25c as output port identifying means.

The counter circuit 25d has a reset node RST coupled to the synchronous signal line SYNC and is incremented by the system clock signal. The output signal of the counter circuit 25d is fed from the output port Q thereof to the decoder circuit 25b which produces an input bit-map signal B1 to Bn indicative of one of the packet buffer units 201 to 20n in the presence of the most significant bit MSB of the logic "1" level. Since the packet buffer units sequentially supply the respective time slot request signals to the first bus system 26 in synchronism with the system clock signal, the decoder circuit 25b also sequentially designates the packet buffer circuits 201 to 20n, and the decoder circuit 25c produces an output bit-map signal Bn+1 to Bn+m in the presence of the most significant bit MSB of the logic "1" level. For example, if the packet buffer unit 201 receives a packet with the packet header PH designating the output port 241, the decoder circuit 25b produces the input bit-map signal B1 to Bn with bit string of (100...0), and the decoder circuit 25c decodes the packet header PH producing the output bit-map signal with bit string (100...0). However, if the most significant bit MSB is the logic "0" level, each of the input bit-map signal and the output bit-map signal has bit string consisting of "0" bits. The input bit-map signal and the output bit-map signal are supplied to the schedule memory 25a and the circuit arrangement of the schedule memory 25a is shown in detail in Fig. 7. The counter circuit 25e is responsive to the synchronous signal which increments the counting value indicative of the present time or the time slot presently produced. The counter value is supplied to the time slot determination circuit 25g and the subtracter 25i, and a standard time signal TS represents the counting value of the counter circuit 25e. However, detailed description is hereinbelow made with reference to Fig. 8.

Turning to Fig. 7 of the drawings, the schedule memory 25a comprises a plurality of memory cells M11, M1(n+m), Ml1 and Ml(n+m) arranged in (n+m) rows and l columns, a plurality of bit line pairs BL1 to BL(n+m) coupled to the columns of the memory cells M11 to Ml(n+m), a plurality of combined circuits of precharging circuits and column selectors PR1 to PRn+m coupled to the bit line pairs BL1 to BLn+m, respectively, a plurality

of write-in circuits WR1 to WR<sub>n+m</sub> coupled at the opposite ends to the bit line pairs BL1 to BL<sub>n+m</sub>, respectively, an inverter circuit INV70 coupled to the system clock signal line CLK producing the complementary system clock signal, a plurality of word lines W1 to W<sub>l</sub> coupled to the rows of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>), a plurality of word line driver circuits DRV1 to DRV<sub>l</sub>, and a plurality of status sensing circuits SS1 to SS<sub>l</sub> associated with rows of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>). The rows of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>) are coupled to respective reporting lines RPT1 to RPT<sub>l</sub>, and the report lines RPT1 to RPT<sub>l</sub> propagate data bits respectively memorized in the memory cells to the status sensing circuits SS1 to SS<sub>l</sub>. Each of the combined circuit of the precharging circuit and the column selector is hereinbelow simply referred to as "combined circuit". All of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>) are similar to one another, and the precharging circuit PR1 and the write-in circuit WR1 are respectively similar in circuit arrangement to the other precharging circuits and the other write-in circuits. For this reason, description is made on the precharging circuit PR1, the memory cell M11 and the write-in circuit WR1 only for avoiding repetition.

The combined circuit PR1 comprises a series of balancing transistors BLN71 and BLN72 coupled between the component bit lines of the associated bit line pair BL1 for equalizing in voltage level therebetween, and an AND gate AD71 for producing a selecting signal in the co-presence of the bit B1 of the logic "1" level and the system clock signal of the logic "1" level. The memory cell M11 comprises a memory loop of inverter circuits INV71 and INV72, switching transistors SW71 and SW72 coupled between the bit line pair BL1 and the memory loop of the inverter circuits INV71 and INV72 and gated by the word line W1, and a status reporting circuit implemented by a series combination of field effect transistors FET71 and FET72 coupled between the associated reporting line RPT1 and a source of negative voltage level. The field effect transistor FET71 is coupled at the gate electrode thereof to a memory node N71 of the memory loop and turns on in the presence of the logic "1" bit at the memory node N71. The combined circuits PR1 to PR<sub>n+m</sub> are respectively coupled to column selecting lines SE1 to SE<sub>n+m</sub>, and the column selecting lines SE1 to SE<sub>n+m</sub> propagates the selecting signals. The column selecting line SE1 is coupled to the field effect transistor FET72, and, therefore, the field effect transistor FET72 turns on in the presence of the selecting signal on the selecting signal line SE1. The status sensing circuits SS1 has a charging transistor CH711 coupled between a source of positive voltage level V<sub>dd</sub> and the reporting line RPT1, and an inverter circuit INV731. The charging transistor CH711 is gated by the system clock signal line CLK and charges the reporting line RPT1. If the memory node N71 stores the logic "1" bit, the reporting line RPT1 is discharged through the series combination of the field effect transistors FET71 and FET72 in the presence of the selecting signal on

the selecting signal line SE1. However, the logic "0" bit at the memory node N71 allows the reporting line RPT1 to remain the charged state. In this instance, the logic "1" bit at the memory node is representative of a reserved state, and the logic "0" bit of a non-reserved state. As described hereinbefore, when one of the packet buffer units 201 to 20<sub>n</sub> sends the packet header PH of a packet to the time slot scheduling unit 25, the decoder circuits 25b and 25c produce the input bit-map signal and the output bit-map signal, and those bit map signals respectively have the logic "1" bits indicative of the packet buffer unit and one of the output ports 241 to 24<sub>n</sub>. The logic "1" bits incorporated in the bit-map signals cause the AND gates of two combined circuits to yield the selecting signals on the selecting lines SE1 to SE<sub>n+m</sub> in the presence of the system clock signal of the logic "1" level. The reporting line is kept in the pre-charged state only when the non-reserved state is memorized in both of the memory cells corresponding to the packet buffer unit requesting the time slot and the output port to be designated by the packet header PH. The associated inverter circuit INV731, ..., or INV73<sub>l</sub> produces a hit signal HIT1, ..., or HIT<sub>l</sub> of an active logic "0" level on the basis of the reporting line in the charged state. If a combination of a packet buffer unit and an output port is not memorized in more than one rows of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>), more than one status sensing circuits SS1 to SS<sub>l</sub> yield the hit signals.

The hit signal or signals are supplied from the status sensing circuits SS1 to SS<sub>l</sub> to the time slot determination circuit 25g as will be seen from Fig. 6, and detailed description will be hereinafter made on the time slot determination circuit 25g with reference to Fig. 8. The rows of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>) respectively correspond to a series of time slots, and more than one high signal means that more than one time slot are available. However, only one row of the memory cells M11 to M<sub>l</sub>(<sub>n+m</sub>) is activated by the associated word line driving circuit DRV1, ..., or DRV<sub>l</sub>, and the memory cells in the activated row memorize the reserved state by the write-in circuits associated with the columns corresponding to the packet buffer unit requesting the time slot and the output port designated by the packet header PH. This means that one of the time slot is reserved by a new packet which arrives at the packet buffer unit. The reservation will be hereinafter described in detail.

Turning to Fig. 8 of the drawings, the time slot determination circuit 25g comprises a decoder circuit DEC81, and a plurality of exclusive circuits Ex1, Ex2, ..., Ex<sub>h</sub>, ..., and Ex<sub>l</sub>. The decoder circuit DEC81 is supplied with the standard time signal TS and designates one of the exclusive circuits Ex1 to Ex<sub>l</sub> with a designating signal TOP1 to TOP<sub>l</sub>, and one of the bits of the designating signal TOP1 to TOP<sub>l</sub> goes down to an active logic "0" level for designation.

All of the exclusive circuits Ex1 to Ex<sub>l</sub> are similar in circuit arrangement to one another, and description is made on the exclusive circuit Ex1 only. The exclusive

circuit Ex1 comprises two NAND gates ND81 and ND82, two inverter circuits INV81 and INV82, three AND gates AD81, AD82 and AD83, and a latch circuit LT81. The NAND gates ND81 and ND82, the AND gates AD81 to AD83 and the inverter circuits INV81 and INV82 as a whole constitute a control circuit, and the latch circuit LT81 serves as a storage circuit.

Assuming now that the standard time signal TS and, accordingly, the designation signal indicate that the row of the memory cells M11 to M1(n+m) corresponds to the present time slot, the bit TOP1 is in the active logic "0" level, and the NAND gate ND81 yields the output signal of the logic "1" level regardless of the other input bit. If the hit signal HIT1 is in the active logic "0" level, the inverter circuit INV81 supplies the output signal of the logic "1" level, and the AND gate AD81 writes a piece of assigning information indicative of the assignment of the packet just requesting to the present time slot. In this situation, the NAND gate ND82 yields the output signal of the logic "0" level, and, for this reason, the other exclusive circuits Ex2 to Exl are never responsive to the hit signals even though the hit signals are in the active logic "0" level. However, if the hit signal HIT1 is in the inactive logic "1" level, the AND gate AD81 does not write the piece of assigning information into the latch circuit LT81, but the NAND gate ND82 supplies the output signal of the logic "1" level to the next exclusive circuit Ex2. If the hit signal HIT2 is in the active low voltage level, the piece of the assigning information is memorized in the exclusive circuit Ex2, and no output signal of the logic "1" level is relayed to the next exclusive circuit. In this way, the chance is sequentially relayed from an exclusive circuit to the next exclusive circuit until the earliest time slot is found. The piece of assigning information thus memorized in any one of the exclusive circuits Ex1 to Exl allows the output signal GET1, GET2, ..., GETh, ... or GETl to go to the logic "1" level; but the others remain in the logic "0" level. The output signal of the logic "1" level is encoded by the encoder circuit 25h, and the output signal of the encoder circuit 25h is supplied to the subtracter 25i (see Fig. 6) for producing the time slot assigning signal. The piece of assigning information merely teaches the absolute position of the assigned row, and the subtraction at the subtracter 25i results in a relative position of the assigned row with respect to the row corresponding to the present time slot. For this reason, the time slot assigning signal is indicative of the amount of time delay from the present time or the amount of deviation from the present time slot.

Turing back to Fig. 7, of the drawings, the write-in circuit WR1 comprises a register RG71 coupled to the selecting line SE, four AND gates AD72, AD73, AD74 and AD75 and a write-in buffer circuit BF. The schedule memory 25a is associated with a control unit 25j and a bit map unit 25k. The control unit 25j produces various control signals including an updating signal UPDATE, and the bit map unit provides a bit map signal D1 to

Dn+m to the write-in circuits WR1 to WRn+m. The bit map signal D1 to Dn+m generally has a bit string of (0000...000) but may have another bit string for restricting packets to a particular output port.

The piece of assigning information thus memorized in the latch circuit of one of the exclusive circuits Ex1 to Exl is further used for memorizing the bit combination on the selecting signal lines into one of the rows of the memory cells M11 to Ml(n+m). As described hereinbefore, the piece of assigning information is latched in the exclusive circuit corresponding to the present time slot or the earliest time slot, and description is made on the assumption that the piece of assigning information is memorized in the exclusive circuit Ex1.

When each of the decoder circuits 25b and 25c shifts any one of the bits B1 to Bn or Bn+1 to Bn+m to the logic "1" level, the bits of the logic "1" level cause the AND gates AD71 of one of the combined circuits PR1 to PRn+m to produce the selecting signals of the logic "1" level as described hereinbefore. In the following description, the decoder circuits 25b and 25c are assumed to shift the bits B1 and Bn+m to the logic "1" level. The logic "1" signals on the selecting lines SE1 and SEN+m are memorized in the registers RG71 of the write-in circuits WR1 and WRn+m. After reservation of the memory cell, updating operation is carried out by driving the word line at every clock. However, a rewriting operation is further carried out for a memory cell indicated by one of the bits TOP1 to TOPl in the presence of the updating signal UPDATE in synchronism with the synchronous signal SYNC. If the updating signal UPDATE goes up to the logic "1" level, the output signal of the latch circuit LT81 of the exclusive circuit Ex1 is transferred to the associated one of the rewrite control signal lines WD1, WD2, WDh and WDI in the presence of the bit TOP1 of the active logic "0" level of the designating signal. Then, the output signal of the logic "1" level is supplied from the latch circuit LT81 of the exclusive circuit Ex1 through the AND gate AD83 to the associated rewrite-control line WD1. The rewrite control signal of the logic "1" level causes the associated driver DRV1 to shift the associated word line W1 to an active level, and conduction paths are produced between the bit line pairs BL1 to Bln+m and the memory cells M11 and M1(n+m) in the presence of the complementary system clock signal of the logic "1" level.

For the sake of simplicity, the bit map signal fed from the bit-map unit 25k is assumed to have the bit string consisting of the logic "1" bits, the AND gates AD72 of the write-in circuits WR1 and WRn+m produce the respective output signals of the logic "1" level in the presence of the updating signal UPDATE of the logic "1" level, and the output signals of the registers RG71 incorporated in the write-in circuits WR1 and WRn+m allow the AND gates AD73 and AD75 to yield the respective output signals of the logic "1" level. Since the AND gates AD74 supply the respective output signals of the logic "1" level to the enable nodes of the write-in buffer circuits



BF of the write-in circuits WR1 and WR<sub>n+m</sub> in the presence of the complementary system clock signal of the logic "1" level, the write-in buffer circuits BF are, then, activated and write the logic "1" bit into the memory nodes N71 of the activated memory cells M11 and M1(n+m). The piece of assigning information of the bit combination B1 and B<sub>n+m</sub> is thus memorized in the memory nodes N71 of the memory cells M11 and M1(n+m) and is maintained until the decoder circuit DEC81 designates the row of the memory cells M11 to M1(n+m) again and causes the field effect transistors FET71 to discharge the associated reporting line RPT1. Thus, a series of the bit combinations, each consisting of a bit selected from the input bit map signal B1 to B<sub>n</sub> and a bit selected from the output bit map signal, are respectively memorized in the rows of the memory cells M11 to M1(n+m) by the aid of the time slot determination circuit 25g, and the bit combinations provide the status reporting signals to the time slot determination circuit 25g for assigning a new packet to the earliest time slot.

#### Global Circuit Behavior

Turning to Figs. 9A and 9B of the drawings, the global circuit behavior of the asynchronous transfer mode switching network system shown in Figs. 2 to 8 is described on the assumption that the packet buffer unit 201 accepts a new packet PCK1 with the packet header PH1 designating the output port 24n at time t10. Packet PCK0 has been memorized in the packet memory 201a and is waiting for a time slot SL1 assigned the packet PCK0 by the time slot scheduling unit 25. The time slot SL1 starts with the synchronous signal at time t10.

Upon arrival of the packet PCK1 at time t10, the first counter circuit 201b has the first write-in address at the counter 201i, and the register 201f fetches the first write-in address in synchronism with the synchronous signal at time t10. Then, the counter 201i supplies the first write-in address to the write-in address port WA of the random access memory device 201h, and the first write-in address is sequentially incremented by the system clock signal. With the first write-in address thus sequentially incremented, the random access memory device 201h writes the component bits of the first packets PCK1 therein. When the counting operation on the system clock signal is completed by the interface 201g, the time slot request signal RQT1 indicative of the packet header PH1 is supplied to the first bus system 26 at time t20.

Prior to time t20, the packet PCK0 already written in the packet memory 201a is read out from the packet memory 201a to the associated internal input link 221. Namely, the second read-out address in the third counter circuit 201e reaches a certain value indicative of the memory location where the first read-out address is memorized at time t10, and the first read-out address is supplied from the control memory 201d to the second counter circuit 201c at time t11. The first read-out address is incremented by the system clock signal, and

the component bits of the packet PCK0 is sequentially read out from the random access memory device 201h to the associated internal input link 221.

With the time slot request signal RQT1 supplied to the time slot schedule unit 25 at time t20, the decoder circuit 25b shifts the bit B1 to the logic "1" level, and the decoder circuit 25c allows the bit B<sub>n+m</sub> to be in the logic "1" level. Then, the column selecting lines SE1 and SE<sub>n+m</sub> goes to the logic "1" level. All of the status reporting lines RPT1 to RPT<sub>i</sub> have been already pre-charged before time t20, and mark (\*) stands for the pre-charging operation. Assuming now that the memory cells M11 and M1(n+m) do not memorize the data bits of the logic "1" level and are, accordingly, in the non-reserved state. The status sensing circuit SS1 produces the hit signal GET1 at time t21, and the selecting signals on the column selecting lines SE1 and SE<sub>n+m</sub> are stored in the registers RG71 of the write-in circuits WR1 and WR<sub>n+m</sub>, respectively. If the standard time signal TS designates the row of the memory cells M11 to M1(n+m), the bit TOP1 is in the logic "0" level, and the inverter circuit INV82 inverts the bit TOP1 to the logic "1" level. If the exclusive circuit Ex1 is not supplied with any hit signal GET1, the exclusive circuit Ex1 activates the exclusive circuit Ex1 which is associated with the memory cells M11 to M1(n+m) corresponding to the next time slot SL2. Then, the hit signal GET1 is inverted to the logic "1" level, and the NAND gate ND81 allows the AND gate AD81 to memorize the hit signal in the latch circuit LT81 as the piece of assigning information. The latch circuit LT81 causes the encoder circuit 25 to produce the time slot assigning signal ASG1 indicative of the next time slot SL2 by the aid of the subtractor 25i, and the time slot assigning signal ASG1 is supplied to the control memory 201d.

The time slot assigning signal ASG1 on the second bus system 27 is latched in the interface 201j at time t30, and the adder 201f retrieves the absolute first write-in address through addition between the time slot assigning signal ASG1 and the second write-in address fed from the third counter circuit 201e. With the second write-in address thus retrieved, the random access memory device 201k writes the first write-in address stored in the register 201i and memorizes it as the first read-out address. Though not shown in the drawings, the first read-out address is read out from the random access memory 201k to the second counter circuit 201c in the next time slot SL2 and used for reading-out operation on the packet PCK1 as similar to the packet PCK0.

If the updating signal UPDATE goes up to the logic "1" level at time t40 and the decoder circuit DEC81 shifts the bit TOP1 to the active logic "0" level, the piece of assigning information is read out from the latch circuit LT81, and the AND gate AD83 shifts the rewrite control line WD1 to the logic "1" level. The bit line pairs BL1 to BL<sub>n+m</sub> are precharged at timing indicated by (\*), and the word line driving circuit DRV1 allows the word line W1 to go up to the logic "1" level in the presence of the



rewrite control signal WD1. With the selecting signals already memorized therein, the registers RG71 of the write-in circuits WR1 and WRn+m causes the write-in buffer circuits BF to drive the bit line pairs BL1 and BLn+m, thereby writing the data bits of the logic "1" into the memory cells M11 and M1(n+m) at time t41. This write-in operation is represented by mark (\*\*).

As will be understood from the foregoing description, the asynchronous transfer mode switching network system according to the present invention assigns all of the packets to the respective time slots upon arrival at the packet buffer units, and this results in improvement of the throughput. In fact, if the asynchronous transfer mode switching network system according to the present invention has  $n$  packet buffer units as many as the output ports, the throughput is improved as shown in Fig. 10. Moreover, the asynchronous transfer mode switching network system is implemented by complementary MOS inverters fabricated with 1.2 micron design rule and is well responsive to the system clock signal at 20 MHz.

#### Claims

#### 1. An asynchronous transfer mode switching network system comprising:

- a) a plurality of input ports (211 to 21n) each supplied with a series of packets, each of said packets having a piece of port address information indicative of a destination;
- b) a plurality of packet buffer units (201 to 20n) coupled to said input ports (211 to 21n), respectively, each of said packet buffer units (201 to 20n) having a plurality of memory locations for storing said packets fed from the associated input port, respectively;
- c) a plurality of output ports (241 to 24m) each serving as said designation; and
- d) a space division switching unit (23) coupled between said packet buffer units (201 to 20n) and said output ports (241 to 24m) and providing a plurality of signal paths each coupling one of said packet buffer units (201 to 20n) and one of said output ports (241 to 24m) designated by said piece of port address information incorporated in each packet fed from said one of said packet buffer units (201 to 20n),

#### characterized by

#### e) a time slot scheduling unit (25) including

- e-1) a packet buffer identifying sub-unit (25b) for producing a first identifying signal indicative of one of said packet buffer units sending a time slot request signal to said time slot scheduling unit (25) when one of said packets arrives at

said one of said packet buffer units (201 to 20n), e-2) an output port identifying sub-unit (25c) for producing a second identifying signal indicative of one of said output ports (241 to 24m) to which said one of said packets is directed,

e-3) a schedule memory (25a) having a plurality of memory locations respectively corresponding to a series of time slots and memorizing pieces of combinatorial information each indicative of a combination of any one of said packet buffer units (201 to 20n) and any one of said output ports (241 to 24m) reserved by a packet previously supplied to any one of said packet buffer units, said schedule memory (25a) producing a hit signal or signals each indicative of that said memory location does not memorize a piece of combinatorial information indicative of at least said one of said packet buffer units or said one of said output ports (241 to 24m), e-4) a standard time signal producing sub-unit (25e) for producing a standard time signal indicative of a present time slot selected from said series of time slots,

e-5) a time slot determination circuit (25g) supplied with said hit signal or signals and assigning said one of said packets to said present time slot in so far as said memory location corresponding to said present time slot is indicated by said hit signal, said time slot determination circuit (25g) assigning said one of said packets to the earliest time slot with respect to said present time slot in so far as said memory location corresponding to said earliest time slot is indicated by said hit signal upon determination of said present time slot to be non-reserved, and

e-6) a time slot assigning sub-unit (25h/25i) producing a time slot assigning signal indicative of the amount of time delay until said earliest time slot on the basis of an assignment carried out by said time slot determination circuit (25g) and supplying said time slot assigning signal to said one of said packet buffer units (201 to 20n), wherein said one of said packet buffer units (201 to 20n) supplies said one of said packets to said space division switching unit (23) in said earliest time slot.

#### 50 Patentansprüche

#### 1. Schaltnetzwerkssystem mit asynchronem Übertragungsmodus mit:

- a) einer Anzahl von Eingangsanschlüssen (211 bis 21n), denen jeweils eine Folge von Paketen zugeführt wird, wobei jedes der Pakete ein Stück einer Anschlußadressinformation auf-

weist, das ein Ziel angibt,

b) einer Anzahl von Paketpuffereinheiten (201 bis 20n), die mit den Eingangsanschlüssen (211 bis 21n) verbunden sind, wobei jede der Paketpuffereinheiten (201 bis 20n) eine Anzahl von Speicherorten zum Speichern der Pakete aufweist, die von dem jeweils zugeordneten Eingangsanschluß zugeführt würden, 5

c) einer Anzahl von Ausgangsanschlüssen (241 bis 24m), von denen jeder als Ziel dient, und 10

d) einer Raumteilungs-Schalteneinheit (23), die zwischen die Paketpuffereinheiten (201 bis 20n) und die Ausgangsanschlüsse (241 bis 24m) geschaltet ist und eine Anzahl von Signalwegen liefert, von denen jeder eine der Paketpuffereinheiten (201 bis 20n) und einen der Ausgangsanschlüsse (241 bis 24m) koppelt, der durch das Stück der Anschlußadressinformation angegeben ist, das in jedem Paket enthalten ist, das von der einen der Paketpuffereinheiten (201 bis 20n) geliefert wird, 15 20

gekennzeichnet durch

e) eine Zeitfenster-Planeinheit (25) mit 25

e-1) einer Paketpuffer-Identifiziersubeinheit (25b) zur Erzeugung eines ersten Identifizierungssignals, das eine der Paketpuffereinheiten angibt, die ein Zeitabschnitts-Anforderungssignal an die Zeitabschnitts-Planeinheit (25) sendet, wenn eins der Pakete bei der einen Paketpuffereinheit (201 bis 20n) ankommt, 30

e-2) eine Ausgangsanschluß-Identifizier-Subeinheit (25c) zur Erzeugung eines zweiten Identifizierungssignals, das einen der Ausgangsanschlüsse (241 bis 24m) angibt, an den das eine Paket gerichtet ist, 35

e-3) einen Planspeicher (25a) mit einer Anzahl von Speicherplätzen, die jeweils einer Folge von Zeitfenstern entsprechen und Stücke von Kombinationsinformation speichern, von denen jedes eine Kombination von einer der Paketpuffereinheiten (201 bis 20n) und irgendeinem Ausgangsanschluß (241 bis 24m) anzeigt, die durch ein vorher an irgendeine der Paketpuffereinheiten zugeführtes Paket reserviert ist, wobei der Planspeicher (25a) ein Treffersignal oder -signale erzeugt, von denen jedes anzeigt, daß der Speicherplatz ein Stück der Kombinationsinformation, die zumindest die eine der Paketpuffereinheiten oder den einen der Ausgangsanschlüsse (241 bis 24m) anzeigt, nicht speichert, 40 45

e-4) eine Standardzeitsignalerzeugungssubeinheit (25e) zur Erzeugung eines Standardzeitsignals, das ein momentanes Zeitfenster angibt, das aus der Folge von Zeitfenstern 50 55

ausgewählt ist,

e-5) eine Zeitfenster-Bestimmungsschaltung (25g), die mit dem Treffersignal oder den -signalen versorgt wird und dem einen der Pakete das momentane Zeitfenster insoweit zuweist, als der Speicherplatz, der dem momentanen Zeitfenster entspricht, durch das Treffersignal angezeigt wird, wobei die Zeitfenster-Bestimmungsschaltung (25g) das eine der Pakete dem frühesten Zeitfenster mit Bezug auf das momentane Zeitfenster insoweit zuweist, als der Speicherplatz, der dem frühesten Zeitfenster entspricht, durch das Treffersignal bei der Bestimmung angezeigt wird, daß das momentane Zeitfenster nicht reserviert ist, und

e-6) eine Zeitfensterzuweisungsuntereinheit (25h/25i), die ein Zeitfensterzuweisungssignal erzeugt, das den Betrag der Zeitverzögerung bis zu dem frühesten Zeitfenster angibt, auf Basis einer Zuweisung, die durch die Zeitfensterbestimmungsschaltung (25g) durchgeführt wird, und zum Zuführen des Zeitfensterzuweisungssignals an die eine der Paketpuffereinheiten (201 bis 20n), wobei die eine der Paketpuffereinheiten (201 bis 20n) das eine der Pakete an die Raumteilungs-Schalteneinheit (23) in dem frühesten Zeitfenster liefert.

## 30 Revendications

1. Système de réseau à commutation fonctionnant en mode de transfert asynchrone comportant :

a) une pluralité de ports d'entrée (211 à 21n), recevant chacun une série de paquets, chacun desdits paquets ayant une partie d'informations d'adresse de port indicatives d'une destination, 35

b) une pluralité d'unités (201 à 20n) de tampons de paquets couplées auxdits ports d'entrée (211 à 21n), respectivement, chacune desdites unités (201 à 20n) de tampons de paquets comportant une pluralité d'emplacements mémoire pour mémoriser lesdits paquets envoyés à partir du port d'entrée associé, respectivement, 40

c) une pluralité de ports de sortie (241 à 24m) servant chacun de destination, et

d) une unité de commutation par répartition spatiale (23) couplée entre lesdites unités (201 à 20n) de tampons de paquets et lesdits ports de sortie (241 à 24m) et fournissant une pluralité de chemins de signaux couplant chacun l'une desdites unités (201 à 20n) de tampon de paquets et l'un desdits ports de sortie (241 à 24m) désigné par ladite partie d'informations d'adresse de port, incorporée dans chaque paquet envoyé par ladite unité (201 à 20n) de tampon de paquets, 45 50 55

caractérisé en ce qu'il comporte  
 e) une unité de gestion d'intervalles de temps  
 (25) comportant

- e-1) une sous-unité d'identification de tampon  
 de paquets (25b) destinée à produire un pre-  
 mier signal d'identification indiquant l'une des  
 unités de tampons de paquets qui envoie un si-  
 gnal de demande d'intervalle de temps à ladite  
 unité de gestion des intervalles de temps (25) 5  
 lorsque l'un desdits paquets arrive à ladite unité  
 (201 à 20n) de tampon de paquets, 10
- e-2) une sous-unité d'identification de port de  
 sortie (25c) destinée à produire un second si-  
 gnal d'identification indiquant l'un desdits ports  
 de sortie (241 à 24m) auquel est destiné ledit 15  
 paquet,
- e-3) une mémoire de gestion (25a) comportant  
 une pluralité d'emplacements mémoire corres-  
 pondant respectivement à une série d'interval-  
 les de temps et mémorisant des éléments d'in-  
 formations combinatoires, indiquant chacun 20  
 une combinaison de l'une quelconque desdites  
 unités (201 à 20n) de tampons de paquets et  
 de l'un quelconque desdits ports de sortie (241 25  
 à 24m) réservé par un paquet envoyé précé-  
 demment vers l'une quelconque desdites uni-  
 tés de tampons de paquets, ladite mémoire de  
 gestion (25a) produisant un signal ou des si-  
 gnaux de présence indiquant chacun que ledit 30  
 emplacement mémoire ne mémorise pas d'élé-  
 ment d'informations combinatoires indiquant  
 au moins ladite unité de tampon de paquets ou  
 ledit port de sortie (241 à 24m),
- e-4) une sous-unité de production de signal ho- 35  
 raire standard (25e) destinée à produire un si-  
 gnal horaire standard indiquant un intervalle de  
 temps présent, sélectionné dans ladite série  
 d'intervalles de temps,
- e-5) un circuit de détermination d'intervalles de 40  
 temps (25g) recevant ledit signal ou lesdits si-  
 gnaux de présence et assignant ledit paquet  
 audit intervalle de temps présent pour autant  
 que ledit emplacement mémoire correspon-  
 dant audit intervalle de temps présent soit indi-  
 qué par ledit signal de présence, ledit circuit de 45  
 détermination d'intervalle de temps (25g) assi-  
 gnant ledit paquet audit intervalle de temps le  
 plus proche dudit intervalle de temps présent  
 pour autant que ledit emplacement mémoire 50  
 correspondant audit intervalle de temps le plus  
 proche soit indiqué par ledit signal de présence  
 lorsqu'il est déterminé que ledit intervalle de  
 temps présent n'est pas réservé,
- e-6) une sous-unité d'assignation d'intervalle 55  
 de temps (25h/25i) produisant un signal d'assi-  
 gnation d'intervalle de temps indicatif de la du-  
 rée du délai jusqu'audit intervalle de temps le

plus proche sur la base d'une assignation ef-  
 fectuée par ledit circuit de détermination d'in-  
 tervalle de temps (25g) et envoyant ledit signal  
 d'assignation d'intervalle de temps vers ladite  
 unité (201 à 20n) de tampon de paquets, dans  
 lequel ladite unité (201 à 20n) de tampon de  
 paquets envoie ledit paquet vers ladite unité de  
 commutation par répartition spatiale (23) dans  
 ledit intervalle de temps le plus proche.

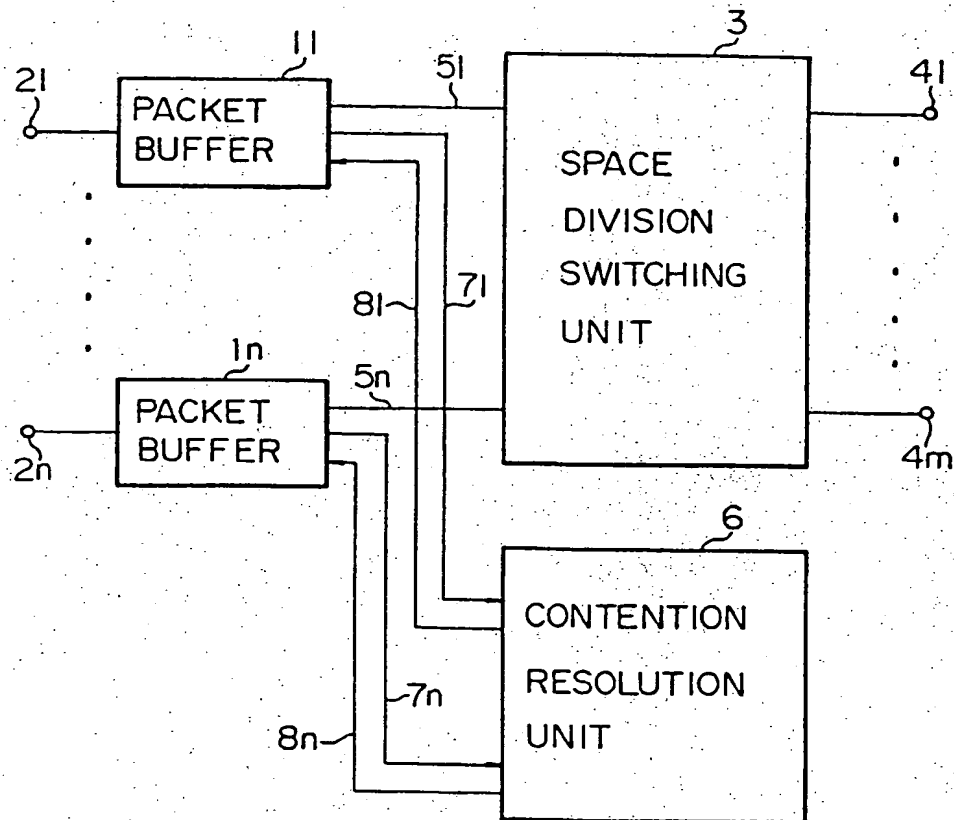


FIG. 1  
PRIOR ART

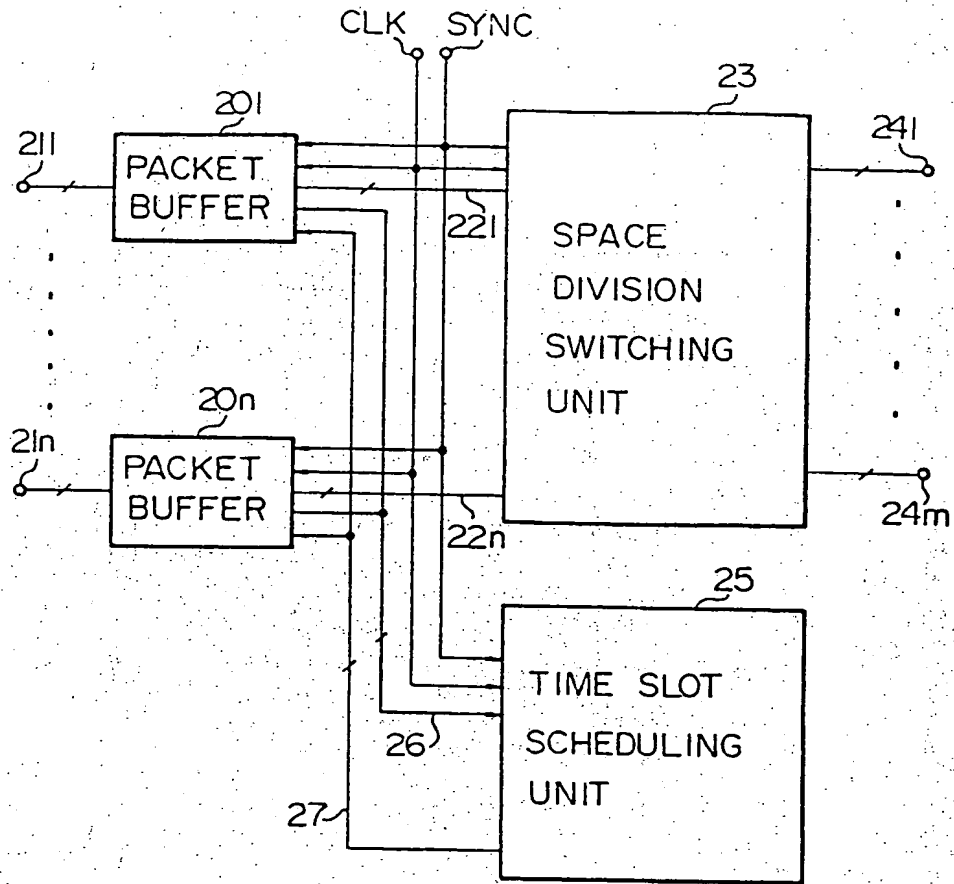


FIG.2

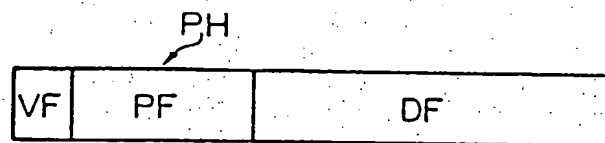


FIG.3

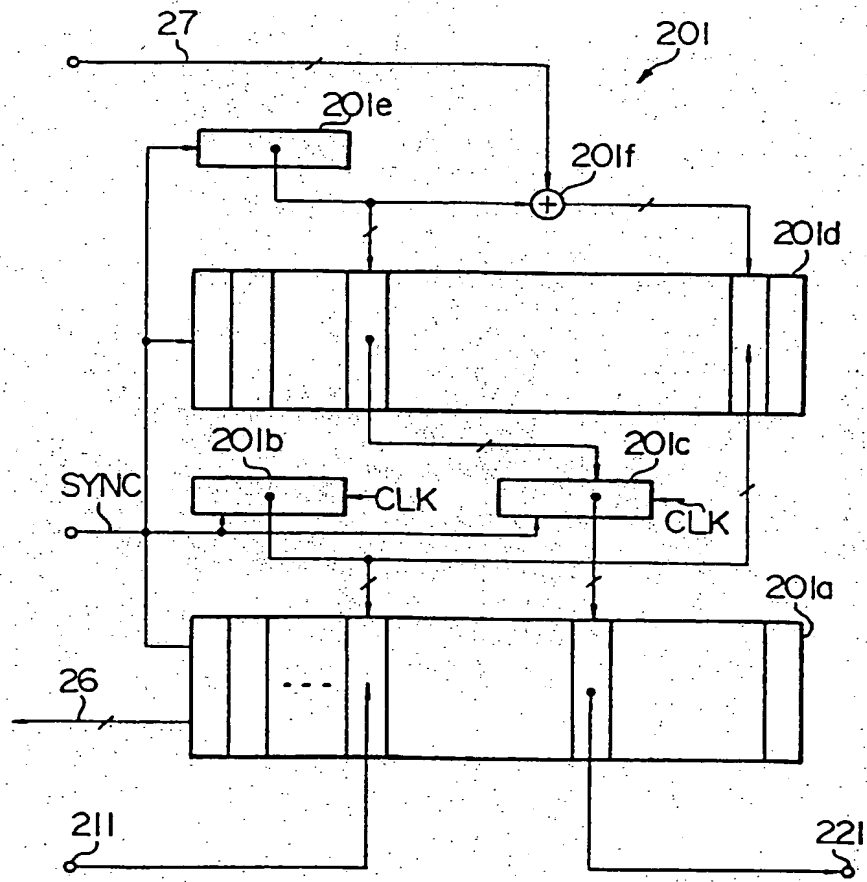


FIG.4

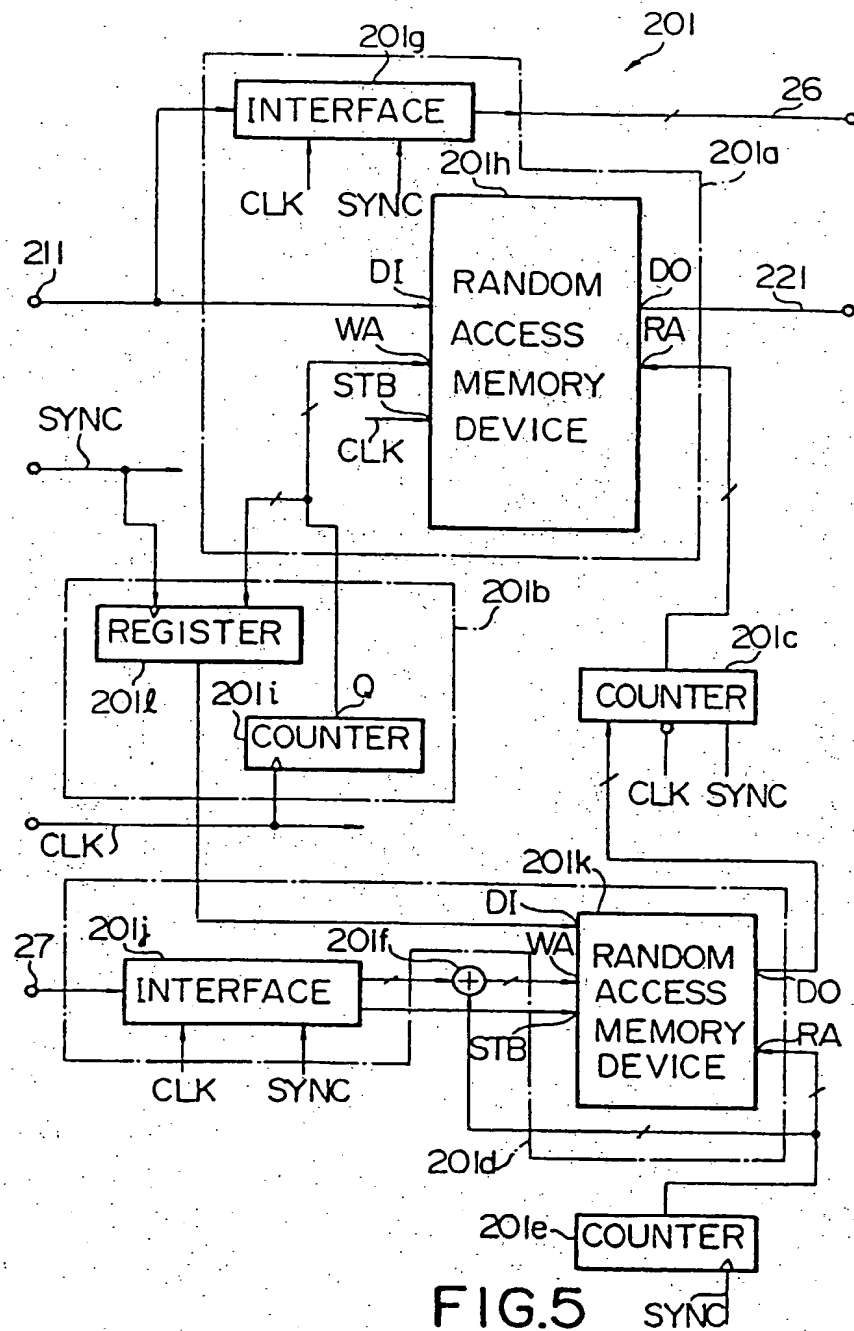


FIG.5



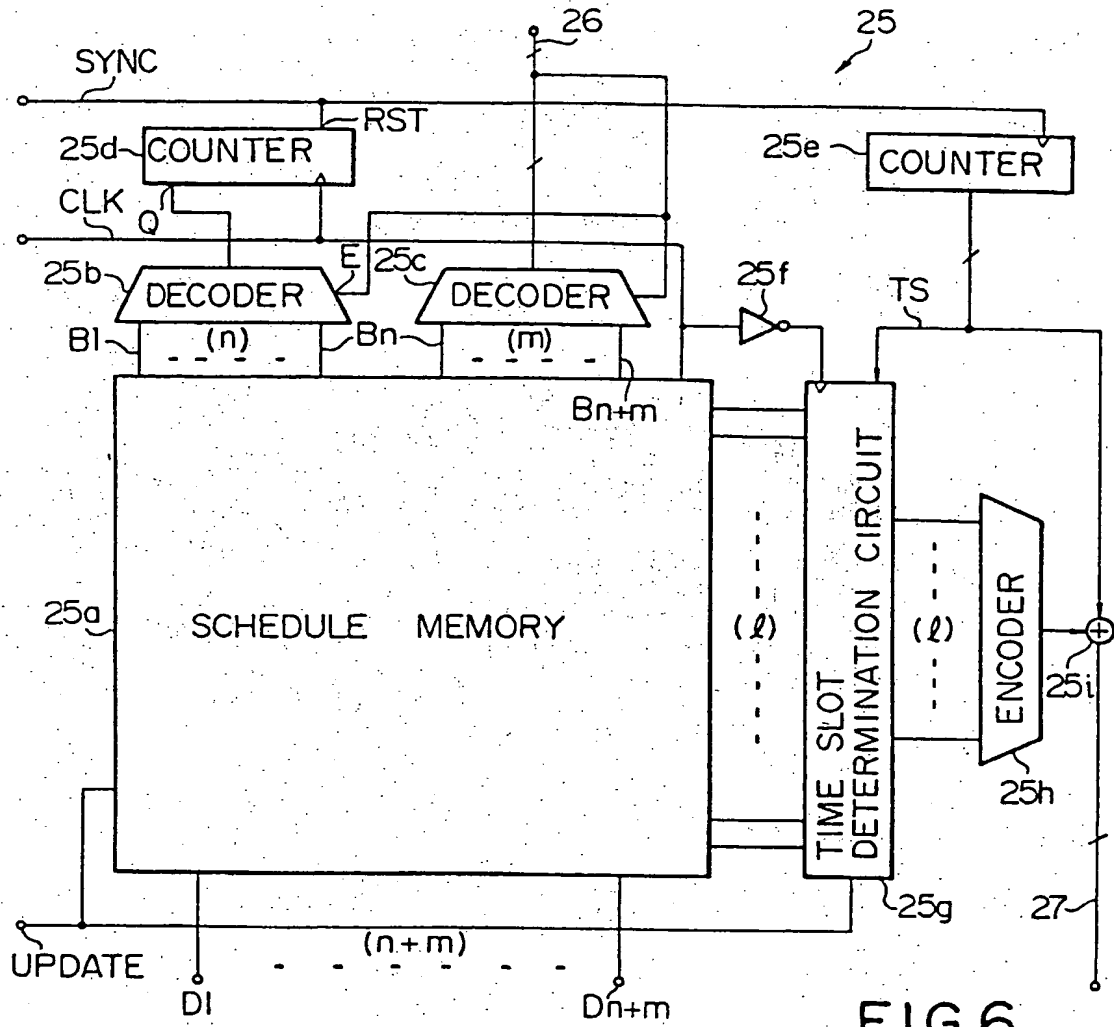


FIG. 6

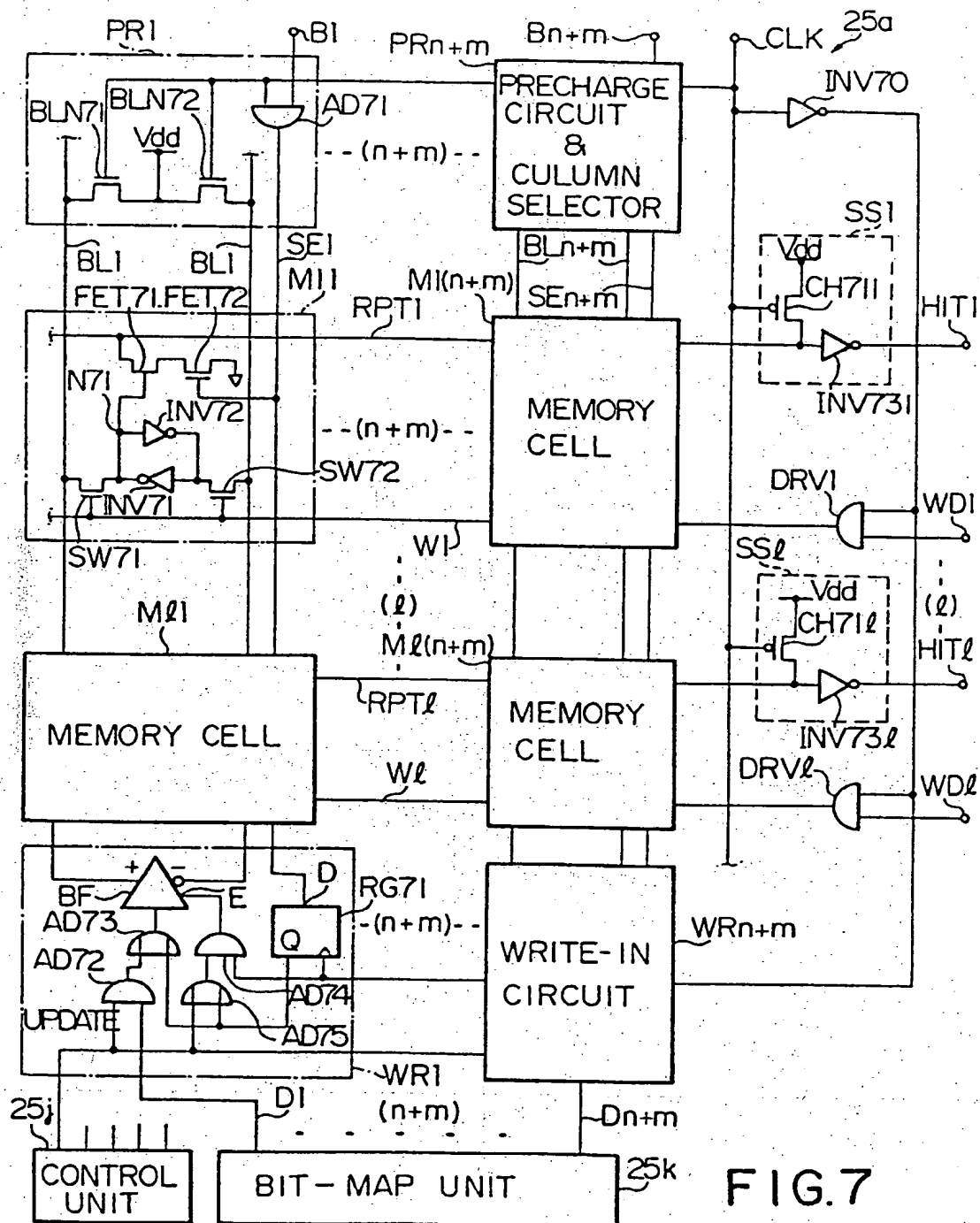
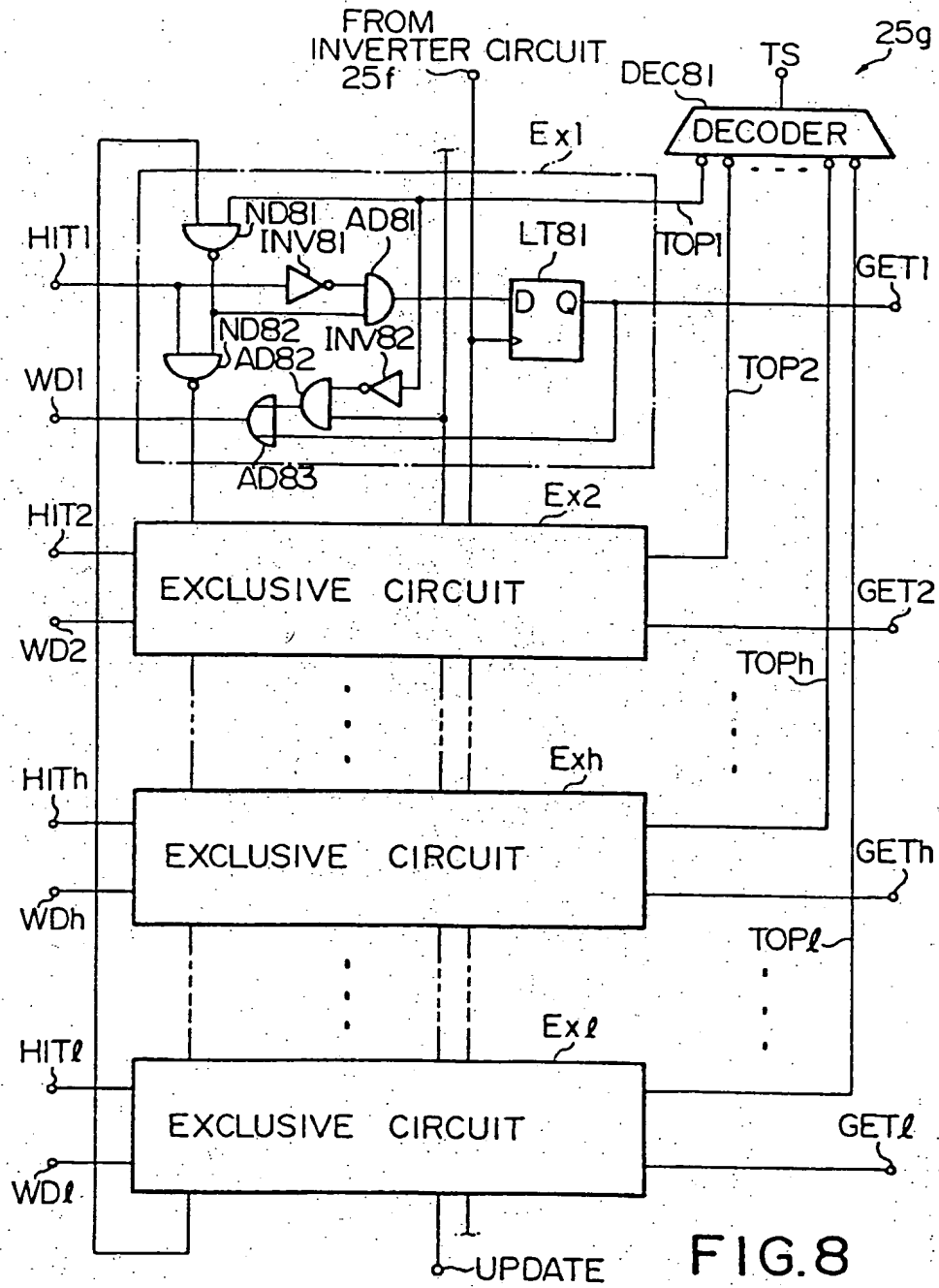
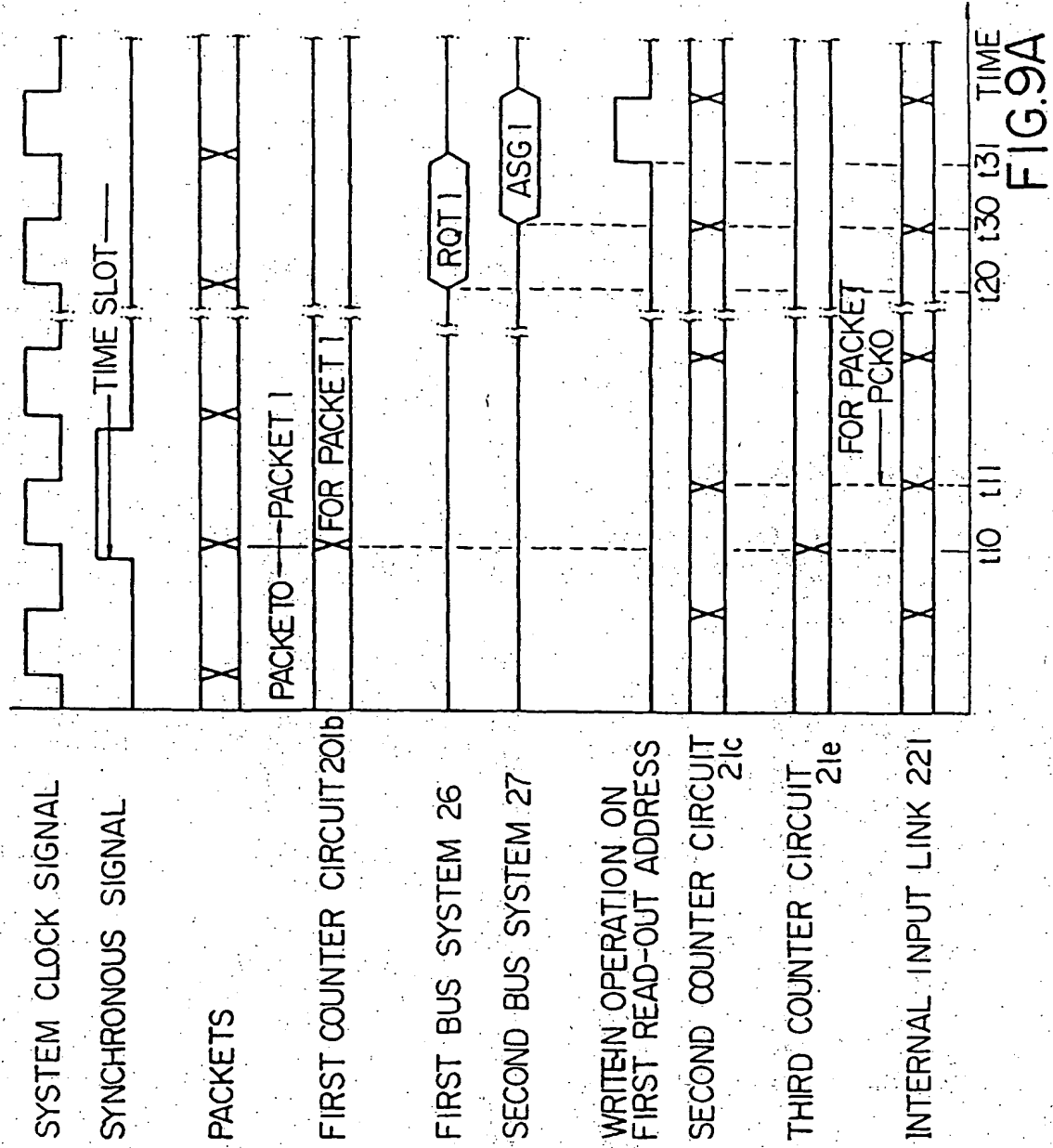


FIG.7





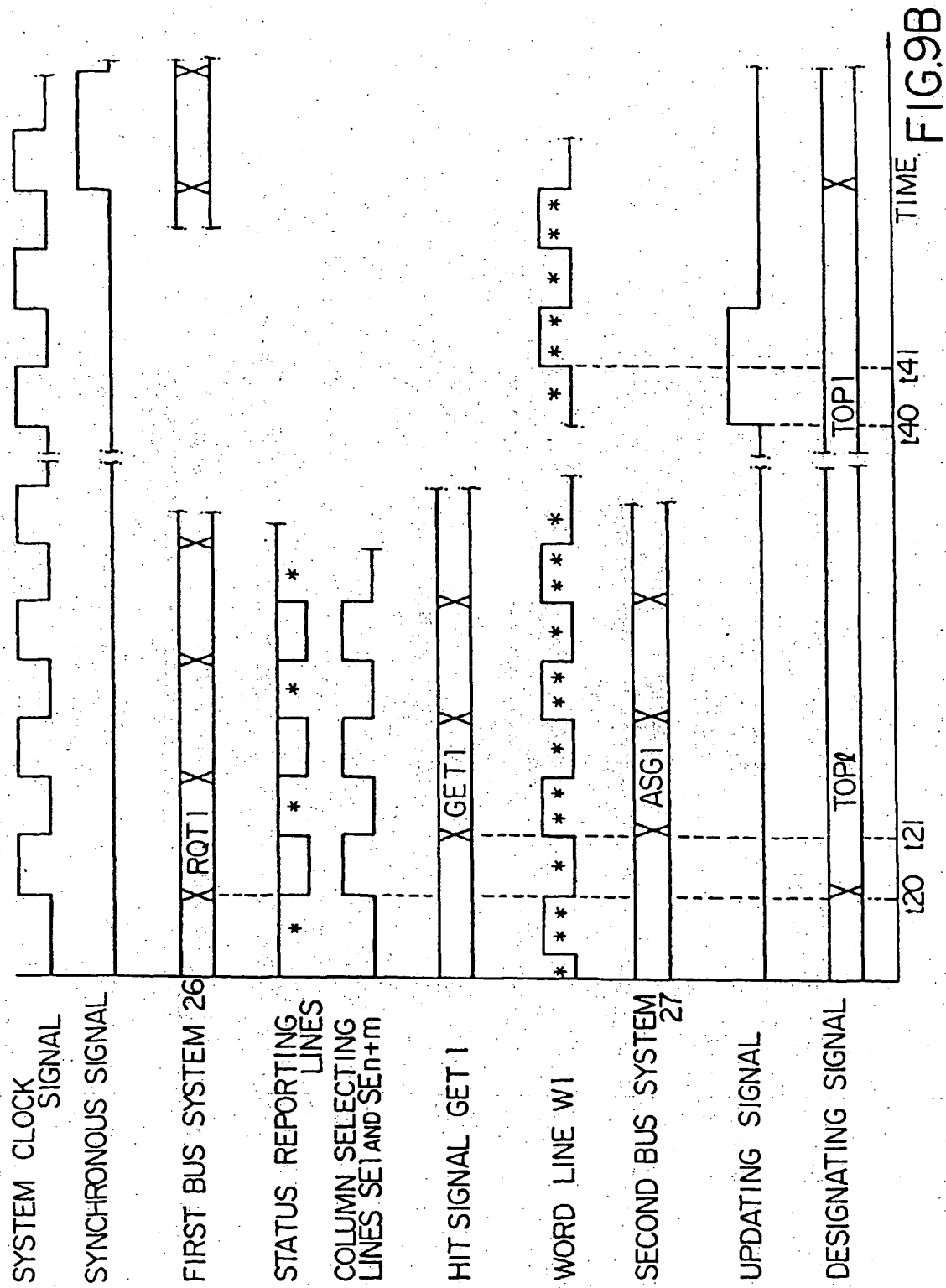


FIG.9B

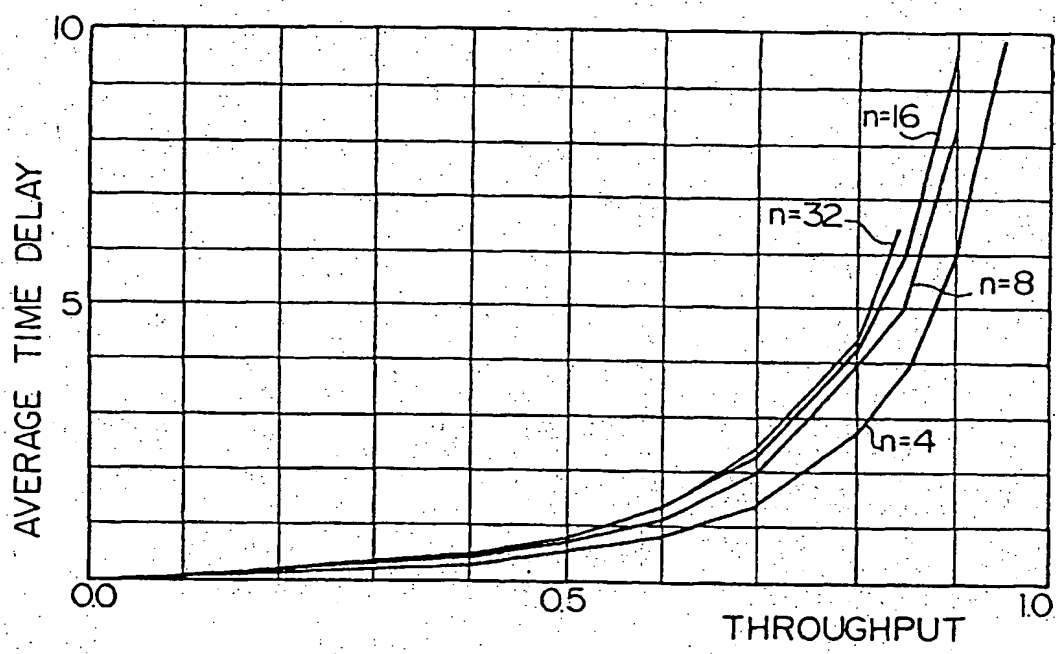


FIG.10

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